An Ocean Ensemble Kalman Filter for Initialization of Seasonal Forecasts

Christian Keppenne, Michele Rienecker, Atanas Trayanov, Robin Kovach and Jelena Marshak

Project Goals and Objectives: To (1) develop algorithms and error covariance models that allow us to optimize the ensemble Kalman filter performance for small-size ensembles and (2) initialize ensembles of coupled seasonal-to-interannual forecasts by assimilating ocean observations into an ensemble of coupled models using an ensemble Kalman filter.

Project Description: A skillful coupled model forecast requires one to effectively minimize initialization shocks. We are addressing this by directly assimilating the observations into the coupled model instead of applying the assimilation to a free-running ocean model prior to coupling.

Because the ensemble Kalman filter (EnKF) evolves an ensemble of model states, it is ideally suited to initialize ensemble forecasts. Our first generation coupled forecasting system was configured such that most ensemble members are initialized by mean of a conventional optimal interpolation analysis applied to the free running ocean model. The application of the EnKF to the free-running ocean model did not originally contribute to the production forecast initialization and only contributes one ensemble member in the current system.

We are in the process of completely reformulating our seasonal forecasting system using GEOS-5 for our second-generation system. The new system is based on the application of an "augmented" EnKF to the GEOS-5 coupled atmosphere-ocean general circulation model (AOGCM). The augmented EnKF assimilates ocean observations and the offline GMAO atmospheric analysis is used to constrain the atmospheric states of the coupled ensemble. The augmented EnKF estimates background error covariances from the current condition of an ensemble of continuous model integration streams and from high-pass filtered past (time-lagged) instances of these same streams. This procedure allows us to artificially increase the ensemble size beyond the limits imposed by current memory and time constraints. The flow-dependent background-error covariance estimates so obtained are augmented with steady-state (i.e., not flow-dependent) covariance information obtained from a static ensemble of estimated model-error and from bred perturbations.

Results: Figure 1 illustrates the coupled assimilation procedure in the case of a one-day ocean assimilation interval. The coupled analysis cycle involves a "replay" of the GMAO atmospheric analysis. **(1)** Following an ocean analysis at 03Z, the AGCM component of each coupled ensemble member is advanced to 06Z (thin black line) where **(2)** the corresponding background (red circle) is differentiated with the atmospheric analysis (blue diamond) which is read from a file to produce an analysis increment. **(3)** The AGCM is then rewound to 03Z and **(4)** the ensemble of coupled models is advanced until 09Z while the atmospheric analysis increments are incrementally applied over the series of time steps from 03Z to 09Z, thereby controlling the drift of the atmospheric states from the atmospheric analysis. The same six-hourly procedure **(1-4)** is then repeated until the time of the next ocean analysis (green star).

The initial testing of the augmented EnKF involves the MOM4 ocean model coupled to the GEOS-5 AGCM. However, a distinct advantage of the new system over its predecessor is that its implementation's reliance on the Earth System Modeling Framework (ESMF) and Modeling Analysis and Prediction Library (MAPL) libraries result in a highly configure-able model-independent data assimilation system (because ESMF and MAPL provide a model-independent framework to connect diverse modeling components).

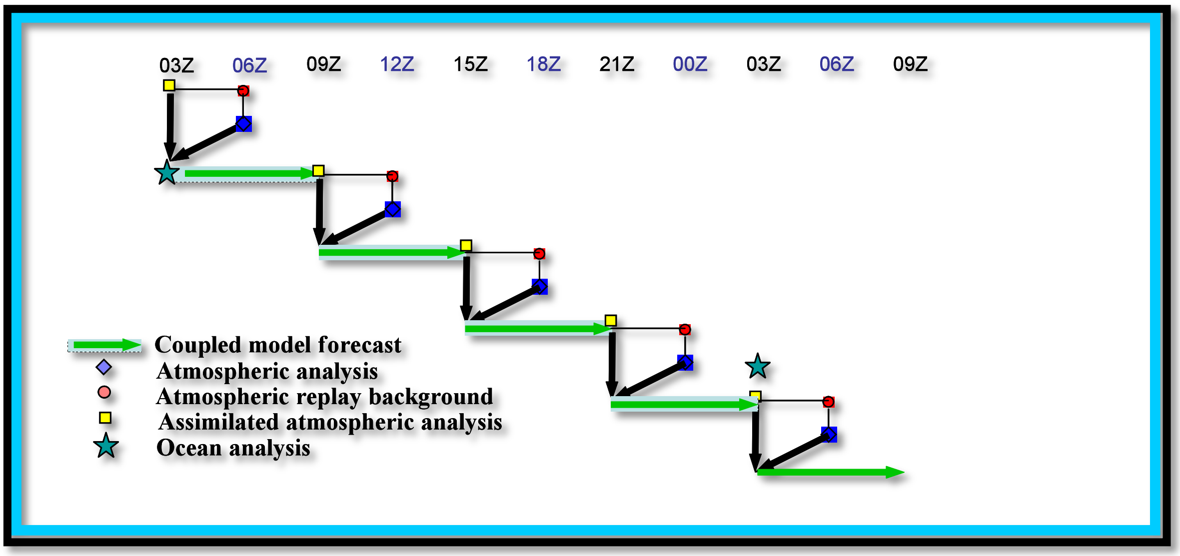

Figure 1: Schematic illustration of the coupled data assimilation procedure with "replay" of the GMAO atmospheric analysis as explained in the text.

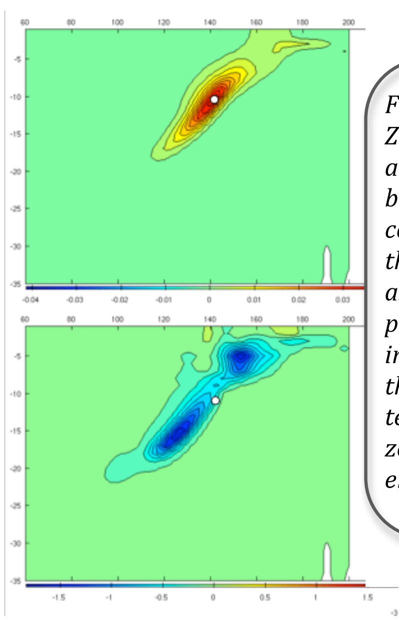

Figure 2: Zonal sections through an adaptively localized background error covariance function showing the influence (marginal assimilation increment) of a positive unit temperature innovation at the location of the white circles on (top) the temperature and (bottom) zonal current fields of one ensemble member (see text).

The EnKF implementation includes a flow-adaptive background error covariance localization and filtering procedure to mitigate the deficiencies of a limited-size ensemble. The localization for the compact support is based on neutral density. As an illustration, a zonal vertical section through an adaptively localized error covariance is shown in Figure 2. This covariance shows the marginal impact of a unit temperature innovation at a location indicated by the white circle on the temperature field of one ensemble member (upper panel). Note the tilt of the covariance pattern, which approximately follows the thermocline. The influence of the same temperature innovation on the other model prognostic fields obeys similar stratification-aware patterns. The lower panel shows the corresponding marginal zonal current increment.

Publication:

Keppenne, C.L., M.M. Rienecker, J.P. Jacob and R.M. Kovach, 2008: Error covariance modeling in the GMAO ocean ensemble Kalman filter, *Mon. Wea. Rev.*, **136**, 2964-2982.